ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

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Final Report On

PROJECT NO. T-9 - NDRC Infra-red Gas Analyzer for Determination of Rapidly Changing Carbon Monoxide Concentrations

Project No. T-9

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18 May 1945

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U. S. Armored medical research
laboratory, Fort Knox, Ky.
Project no. T-9

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. T-9
SPMEA 723.13-1

18 May 1945

NDRC INFRA-RED GAS ANALYZER FOR CARBON MONOXIDE

1. PROJECT: No. T-9 - Final Report on the NDRC Infra-red Gas Analyzer for Determination of Rapidly Changing Carbon Monoxide Concentrations.

a. Authority: Reported for record. Work completed in connection with previously reported studies of control of gun fumes in armored vehicles.

b. Purpose: To describe the performance characteristics and usefulness of the subject instrument, particularly in the study of gun fumes in tanks.

2. DISCUSSION:

The contamination of tank atmospheres which result from firing of the large caliber weapons is characterized by rapid changes in concentration of the gun fumes. There has been available no indicating or recording device for carbon monoxide, the major contaminant in the fumes, which had a sufficiently rapid response time to follow these changes without serious lag. This necessitated the use of a laborious and time-consuming technic of frequent collection of samples in evacuated glass flasks at short and carefully timed intervals. Consultation with Section 17, NDRC, revealed that an instrument was under development which gave promise of filling our requirements. Further development, consultation and field tests led to the present instrument, which, in various stages of development, has been in use for nearly two years. The performance characteristics are discussed in detail in the Appendix.

3. CONCLUSIONS:

a. The subject instrument is sufficiently reliable and stable to be practical for field use.

b. The rapid response time of the instrument permits adequate description of the varying carbon monoxide concentration in tank atmospheres resulting from firing of the tank weapons.

4. RECOMMENDATIONS: None

5. ACKNOWLEDGEMENT:

The active cooperation of NDRC, particularly Messrs. Bragg, Fastie and

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Stewart, in the development of an instrument to meet the peculiar needs of gun fume studies is acknowledged.

Submitted by:

Norton Nelson, Major, SnC

APPROVED Willard Machle

WILLARD MACHLE
Colonel, Medical Corps
Commanding

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#1 - Appendix
#2 - Figs. 1 thru 5

APPENDIX

1. Description:*

a. The subject instrument is based on the selective absorption by carbon monoxide of radiation in the infra-red region of the spectrum. In the present instrument infra-red radiation, which is emitted by an electrically heated nichrome coil, passes across a test chamber through which the gas sample is continuously pumped. After leaving the test chamber the beam of radiation is split into two parts. Each half of the beam passes through one part of an axially divided filter chamber, and then onto the two sections of a balanced thermopile. The instrument achieves its carbon monoxide selectivity by the fillings of the filter chambers. One of these is normally filled with carbon monoxide and the other with a non-absorbent gas, such as oxygen. Hence, the radiation falling on the two halves of the thermopile is unequal by the amount of the radiation removed by the carbon monoxide. This imbalance is compensated (with the test chamber filled with non-absorbing gas) by the application of a constant D.C. component before the thermopile output is amplified. Amplification is accomplished by means of a breaker type D.C. amplifier which actuates a strip chart recorder.

b. When a gas containing carbon monoxide enters the test chamber the radiation falling on the half of the thermopile behind the oxygen-containing filter chamber is reduced. Since the radiation that falls on the half of the thermopile behind the carbon monoxide filled filter cell is already maximally attenuated in the spectral region where carbon monoxide absorbs, no further reduction in radiation intensity occurs, therefore, in this half of the beam. This reduction in the radiation intensity on half the thermopile is reflected in a change in output and thus causes a proportionate deflection on the recorder.

c. In the case of a gas having an absorption band in the infra-red, but sufficiently separated from the carbon monoxide band so as not to overlap, equal reductions in radiation intensity occur on both halves of the thermopile and no deflection results. Conversely, those gases having bands that overlap the carbon monoxide band will produce a deflection just as does carbon monoxide. The extent of such interference is a function of the degree of band overlapping. From a practical standpoint, the chief possibilities of interference with carbon monoxide measurement are from water vapor and carbon dioxide, both of which have absorption bands near that of carbon monoxide. Interference from carbon dioxide can be eliminated by a combination of two means: (1) introduction of equal (low) concentrations of carbon dioxide into both the radiation beams and (2) careful optical balancing. In the earlier models of the instrument the carbon dioxide was introduced as a 10% component into each filter cell; in the most recent model a short separate cell, which includes both optical paths, is filled with pure carbon dioxide. In the case of water vapor, if the interference justifies it, the test gas can be passed through a dryer before entering the test chamber.

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* For a more detailed description of the instrument consult the OSRD Report No. 1642, 1 Jan 1944 entitled "Summary Report Infra-red Gas Detector and Gas Analyzer".

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d. Three sensitivity ranges are provided on the instrument. These are such that 25, 100 and 200 microvolts give full scale deflection of the recorder. The equivalent carbon monoxide concentrations vary with various analysis assemblies, but approximate equivalents would be 0.20, 1.0 and 3.04% carbon monoxide for full scale deflection. In its completed form the analyzer consists of three units: the analyzer proper, the recorder, and the battery supply of two 6-volt storage batteries.

2. Operation:

a. The needle valve and flow meter on the instrument were originally arranged for the use of suction to draw the sampled gas into the chamber. Since a positive pressure proved more desirable for our application, the necessary rearrangement of needle valve and flow meter connections were made to permit this. A small motor-driven pump* is used between the sampling line and the sample chamber to drive the test gas through the instrument. This pump has a nominal capacity of 1.3 cfm; with 25 feet of $\frac{1}{4}$ inch ID rubber tubing on the inlet side of the pump, the capacity is about 25 liters/min. Of this, 10 liters/min. passes through the desiccant tube into the test chamber, the remainder being vented at the pump. The use of a high rate of flow through the tubing upstream from the pump minimizes time lag from the sampling point to the test chamber.

b. Since the most frequent sampling point in tank gun fume studies is at the breathing zone of a crew member, moisture laden air from the expired air of crewmen frequently enters the sampling line. At high levels of carbon monoxide the deflection produced by the moisture is negligible; however, at low levels it may become troublesome. To avoid this difficulty a desiccant upstream from the test chamber has been uniformly employed. For this purpose, Charcalite (a CWS charcoal impregnated with calcium chloride) has proven very satisfactory. In a tube 10 inches long by one inch in diameter, one charge will last 6 to 8 hours at 10 liters/min. under ordinary humidity conditions.

3. Performance:

a. Warm-up time: For some time after turning on the instrument there is a zero drift which requires several hours to stabilize. This is illustrated in Record 1, Fig. 1. In this record the zero drift had slowed considerably in $1\frac{1}{2}$ hours and is virtually gone in 2 hours. Since the need for the instrument can ordinarily be anticipated, this delay is not a serious handicap.

b. Calibration: Typical calibrating deflections are shown in Record 2, Fig. 1. This record illustrates the two standardizing adjustments which are made before, and maintained during, use. The first, labelled "STD", involves adjustment of the heater current and bucking potential (both are from the same source so that proper adjustment fixes both at their correct value) to the standard value. The second, labelled "Test", involves adjustment of the amplifier gain so that a standard test signal produces a predetermined deflection on the recorder.

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* Gas pump #2NF10-V with the oiler and muffler removed.

Calibration is carried out with carbon monoxide mixtures in oxygen stored in high pressure cylinders and standardized by the iodine pentoxide method of CO analysis. Periodic recheck of such mixtures has been found necessary. Five mixtures are employed, consisting of nominal concentrations of 0.05%, 0.15%, 0.30%, 0.60% and 1.0% carbon monoxide by volume. Ordinarily the calibration base line is obtained with cylinder oxygen. However, oxygen or air may be used interchangeably if a desiccant is employed in the line.

A typical complete calibration curve is shown in Fig. 2. The calibrations have uniformly followed an equation of the type:

$$C = K_1 \log \frac{K_2}{K_2 - E}$$

where, C = carbon monoxide concentration

K_1, K_2 = constants

E = microvolts deflection

The stability of calibration with time appears to depend largely on the extent of leakage of the filter cone. One model of cone which had a rubber gasket cemented between the window and the cell showed rapid loss of sensitivity. Where the window is cemented directly to the cell, loss of sensitivity is quite slow and does not ordinarily exceed a few per cent per month. For convenience in analysis of the records obtained with the instrument, the practice has been to transfer the calibrations to a transparent plastic template which has drawn on it a base line and time scale markings to conform with the record paper. This template is placed over the record and the carbon monoxide concentrations read directly. In order to avoid frequent redrawing of these templates as the calibration changes, advantage is taken of the sensitivity control on the instrument to maintain the sensitivity at the initial level by suitable adjustment. Because of the uniformity of the calibration curve, checking with a single CO concentration is adequate in making such readjustments.

c. Interfering gases: Fig 3 illustrates the relative deflections of CO, CO_2 and H_2O for various settings of the optical balance. It can be seen that, even without compensating adjustment, the relative deflections given by H_2O and CO_2 are small. Also it is evident that the instrument cannot be compensated for the two gases simultaneously. Consequently the normal procedure is to adjust for CO_2 compensation, and dry the gas where water vapor interference is serious.

The data shown in Fig. 3 were obtained with an analysis cone which had 10% CO_2 in each chamber. Similar results, except that the slope of the CO_2 line is slightly lower, are obtained with the newer type of CO_2 compensator in which a short column of pure CO_2 is interposed in both radiation beams.

Even for perfect CO_2 compensation, a transient deflection occurs when CO_2 is introduced into the analysis chamber. This is illustrated in Fig. 1, Record 2. The magnitude of this artifact varies with different instruments. Possible causes for this artifact may be non-symmetrical introduction of CO_2 into the analysis chamber, or differences in the response times of the two thermopile elements.

d. Response Time: Fig. 4 illustrates the rate of response of the instrument under several conditions of use. Two methods of sample introduction were used, (1) the calibrating procedure, in which the gas went directly from a high pressure cylinder to the instrument through 6 feet of ¼ inch ID tubing, (2) the field sampling system, consisting of 26 feet of ¼ inch ID tubing, Pump, 6 feet

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¼ inch tubing, and desiccant unit. The air flow through the analysis cell was 10 liters/min. in each case, but the flow through the 26 feet of line and pump in the field arrangement was 25 liters/min. The chart indicates that there is practically no loss in response time with the field sampling arrangement. However, there does appear to be a definitely more rapid approach to the base line than to a CO deflection. In all cases response was 90% complete in 10 seconds.

Another measure of response time is given by the maximum frequency of CO pulses which can be resolved by the instrument. This is illustrated in Records 3 through 6 in Fig. 1. In Record 3, a single pulse resulting from a single round of 75 mm fire in a tank is shown. Record 5 shows the CO concentration resulting from successive rounds fired at 10 second intervals under identical conditions; pulses are readily resolved. In Record 6, the firing rate has been increased to one every 5 seconds, and it is apparent that the instrument has failed to resolve pulses occurring at this frequency. Record 4 shows excellent resolution of a 10 second rate of fire that was simulated by releasing 10 liters of a 30% CO mixture* at the breach of the tank gun at the 10 second intervals. The improved uniformity of the pulses over the actual run shown in Record 6 may have resulted from the greater stability of the air pattern in the turret during the simulated run, where there were no crewmen moving about during the test.

e. Stability: The instrument is satisfactorily stable if reasonable precautions are taken. These include: allowance of an adequate warm-up period, well charged batteries, and a reasonable degree of protection of the instrument from sudden changes in temperature. In the field, a 3-way stop cock is fitted into the sampling line just upstream from the pump to permit introduction of CO-free air at will. It is the practice to check the base line with CO-free air at frequent intervals. It is ordinarily possible to make such checks about every 10 minutes of operation. It is rare for the zero to drift more than 3 or 4 μ volts in that length of time; generally the drift is considerably less than this. The gun blast, which may be of considerable intensity, does not appear to be an important source of instability.

A potentially dangerous but easily controlled source of instability is electrical leakage from the battery terminals to ground. When batteries which have electrolyte spilled on the case are placed in the metal battery box supplied with the instrument the leakage may be sufficient to make it impossible to put the recorder needle on scale. Great care in cleaning of the batteries is required if they are kept in the metal battery box. The practice of this Laboratory has been to keep the batteries outside the box on a piece of dry plywood.

f. Comparison of Recorder measurements with other types of CO analysis: A number of gun fume trials were carried out in which carefully timed snap samples were collected at the inlet of the sampling line leading to the infra-red instrument. These samples were then chemically analyzed for CO. Some of the results are shown in Fig. 5 where the solid lines represent the CO concentrations measured by the subject instrument and the circles show the findings from

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* Corresponding approximately to the per cent CO and volume of gas released in firing one round.

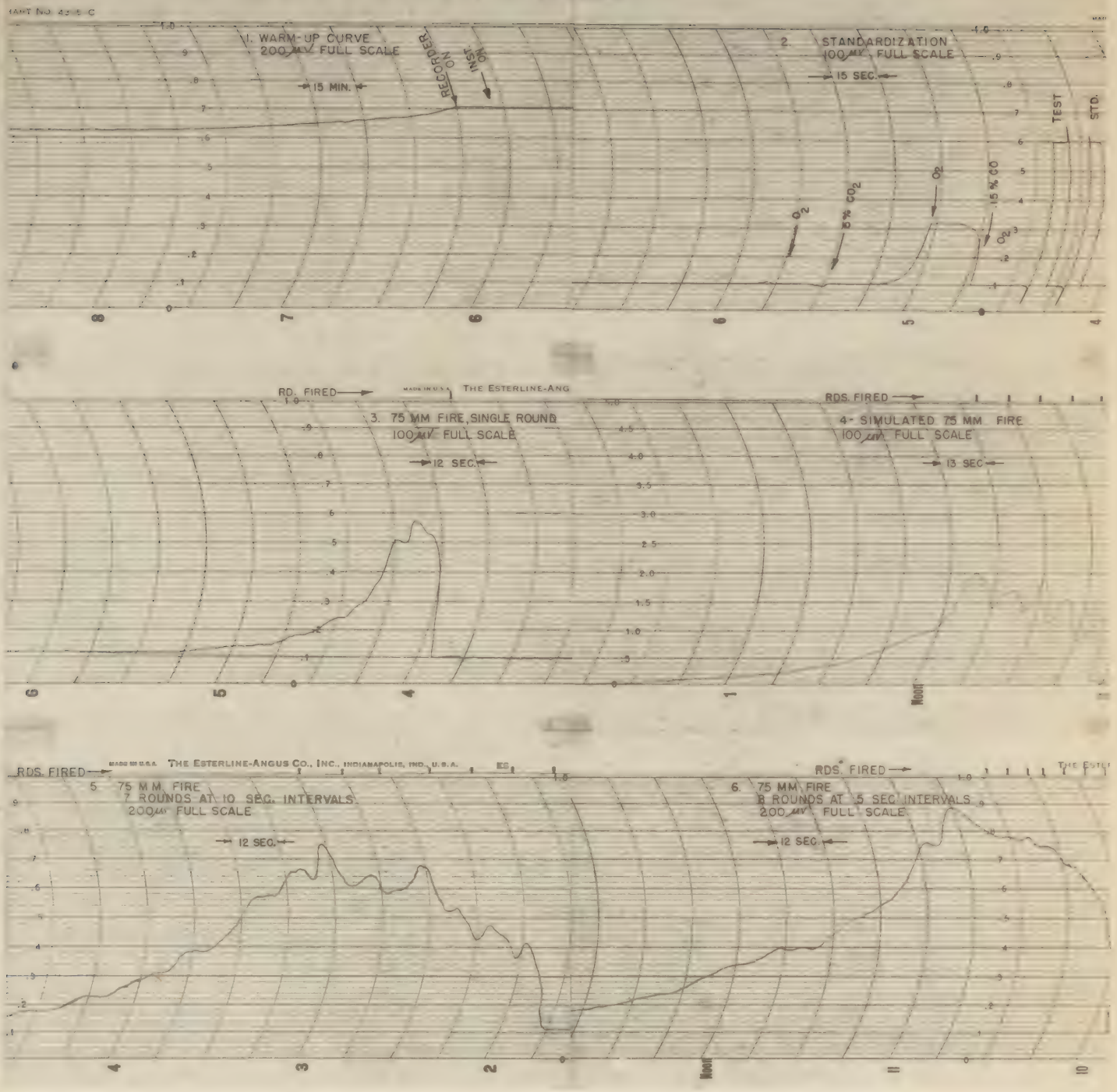
corresponding flask analyses. The agreement between the two methods of measurement is very good if due allowance is made for the lag in the response of the instrument.

In many tests average concentrations have been measured simultaneously by three methods -- the subject recorder, the MSA Indicator, and by chemical analysis of samples collected at constant flow rates in glass bulbs. In general, agreement between the three methods has been satisfactory.

4. Extent of Use:

The favorable response time and the recording feature are uniquely helpful in study of the intermittent fire of the large caliber weapons in tanks. The instrument is also very useful, though not indispensable, in the study of automatic weapons where a more nearly uniform rate of production of CO occurs. The instrument is not practical for use on moving vehicles and in consequence its use by this Laboratory has been limited almost exclusively to tank gun fume trials. In this field it offers three major advantages over other available methods of analysis: (1) By virtue of its rapid response time it eliminates the time-consuming and laborious use of frequent snap samples. (2) It gives a complete and continuous picture of events in contrast to the interrupted incomplete information available from snap samples. (3) By making the results available in the field, immediate changes in experimental design are possible. This leads to considerable time saving in that it permits immediate trial of whatever corrective measures, ventilation modifications, etc., the tests indicate as necessary.

The data most commonly derived from the records of the instrument are: peak concentration, average concentration, and rate of fume clearance. Other types of information are available in the record, but in most instances these three adequately characterize the ventilation characteristics of the tank.



Illustrative Records from the NDRC Infra-red Gas Analyzer

ARMORED MEDICAL RESEARCH LABORATORY

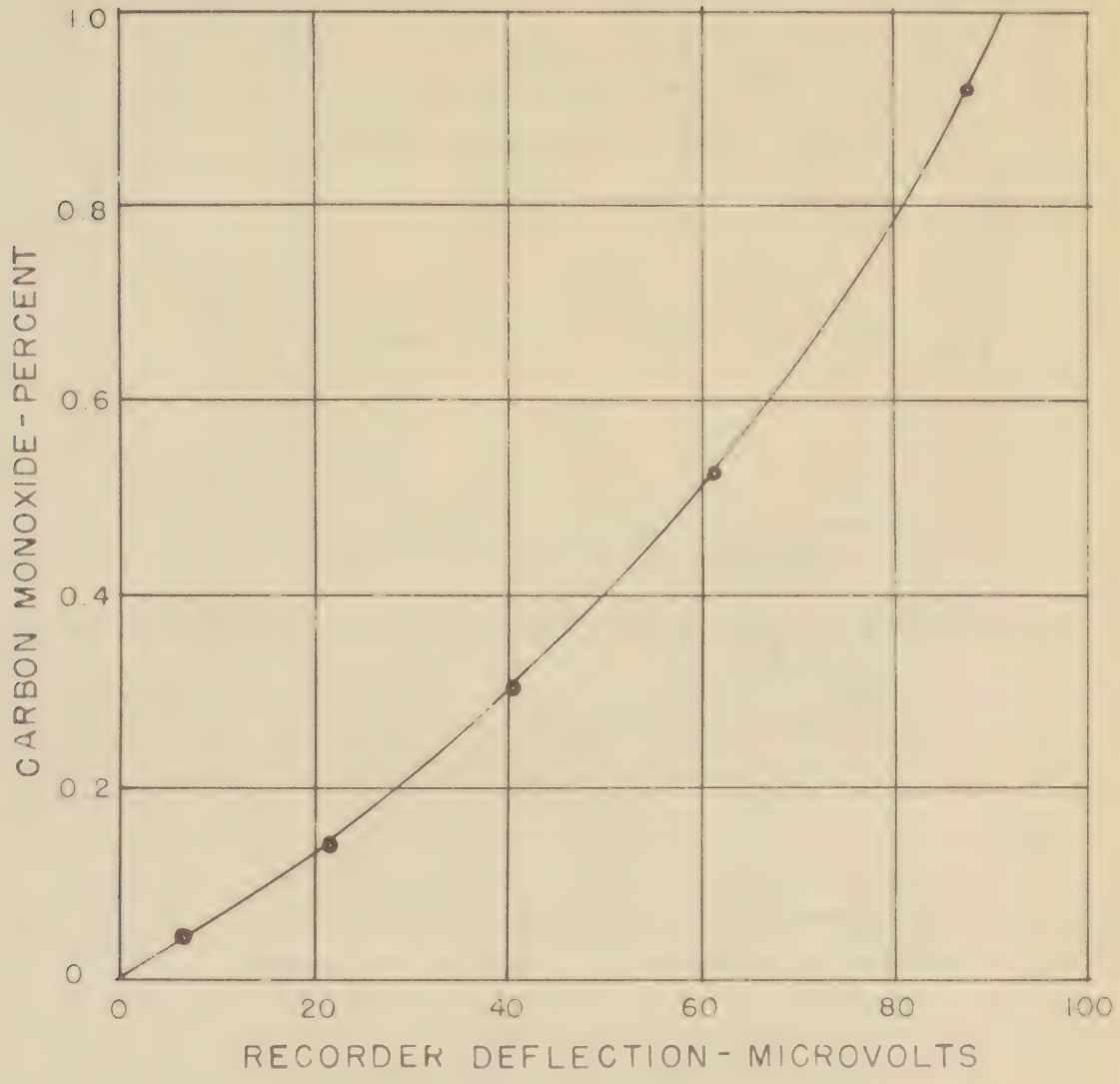
Project No. T-9 FORT KNOX, KY. Fig. No. 1

TYPICAL CALIBRATION CURVE

THIS LINE IS DRAWN ACCORDING TO THE EQUATION $C = 1.78 \log \frac{125}{125 - E}$

C = CARBON MONOXIDE, PERCENT

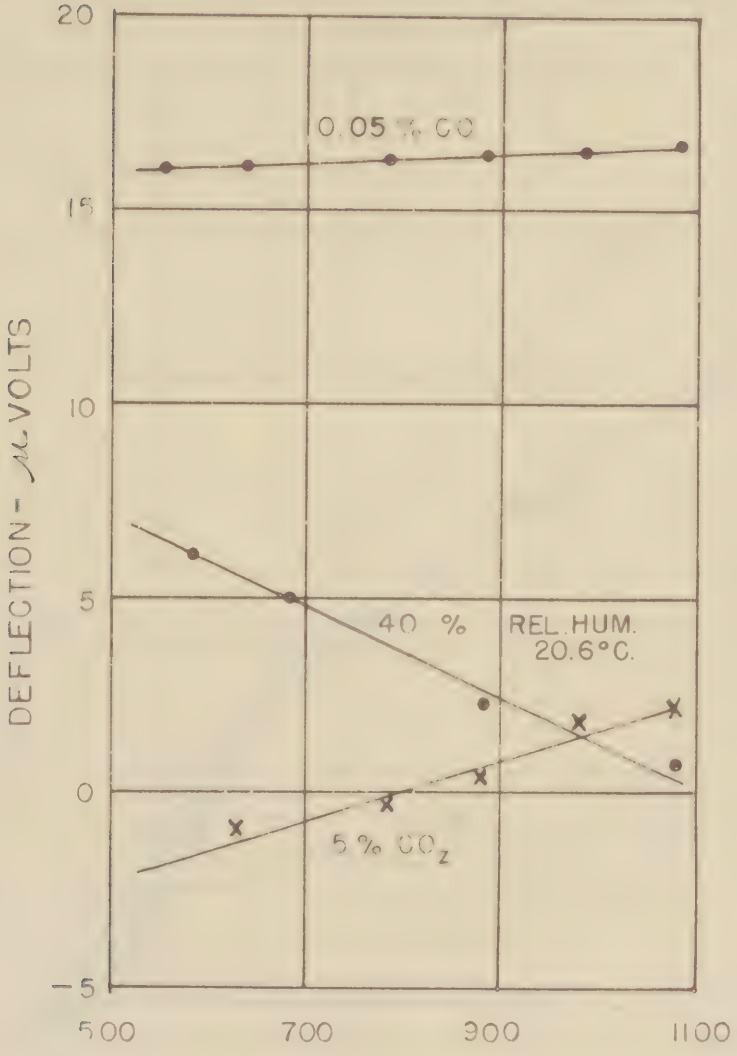
E = DEFLECTION, MV



Incl. #2

FIG. 2

INFLUENCE OF OPTICAL BALANCE ON SENSITIVITY TO CO, CO_2 AND H_2O.



OPTICAL BALANCE IN TERMS OF BUCKING POTENTIAL TO RESTORE ELECTRICAL BALANCE— MICROVOLTS.

FIG. 3

RATE OF RESPONSE

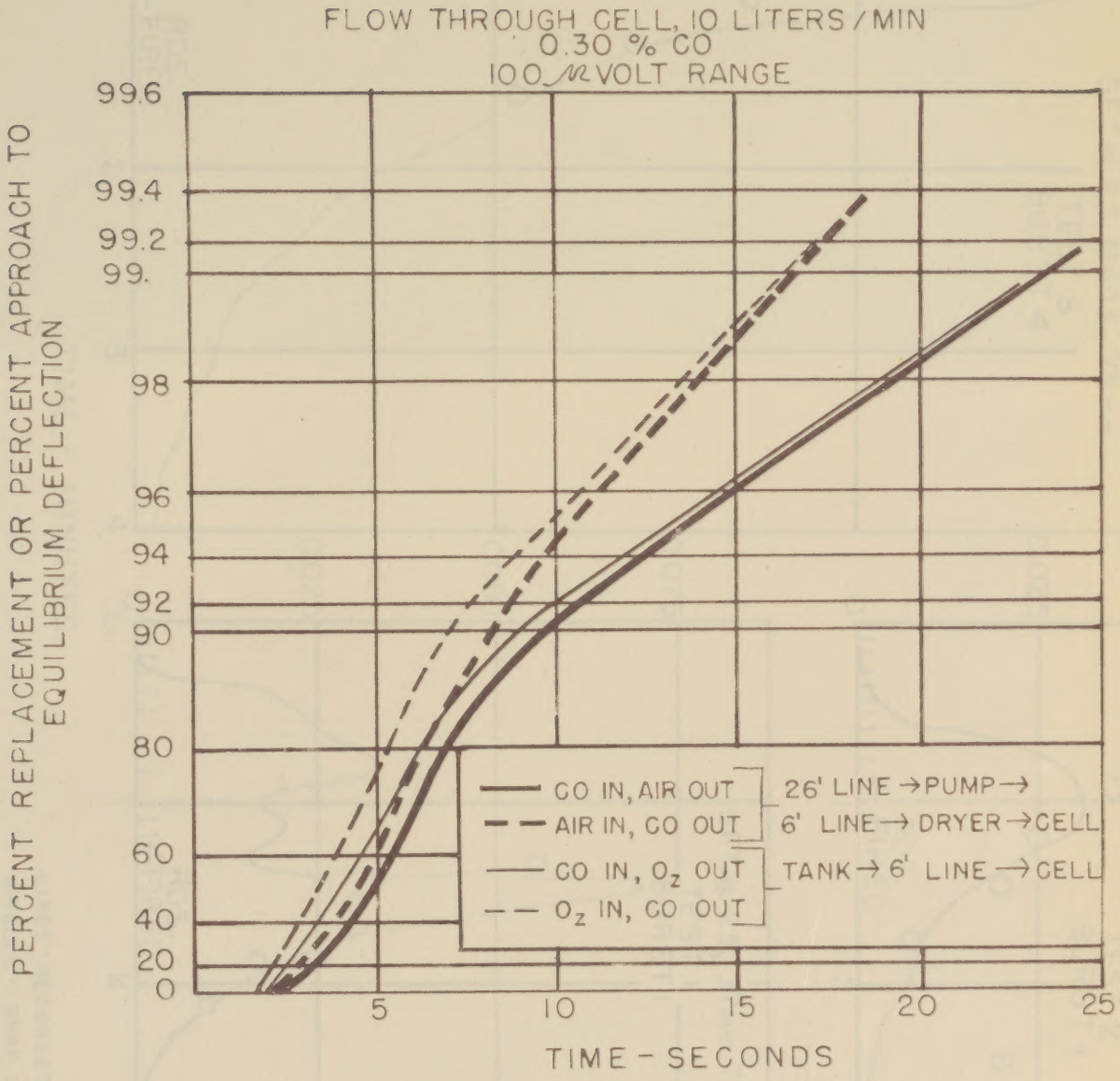
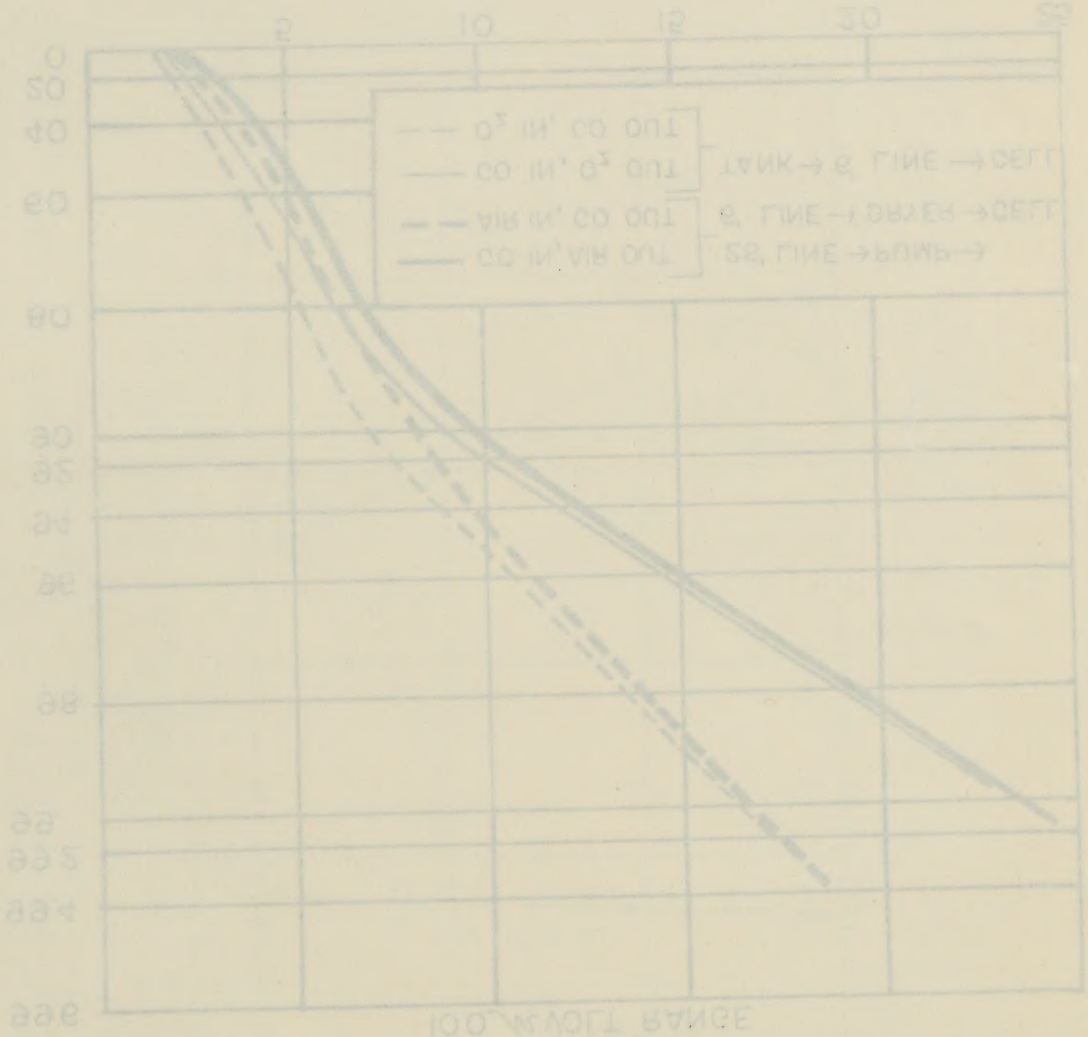


FIG. 4

Incl. #2


TIME - SECONDS
5
10
15
20
25
O
20
40
60
80
90
95
96
98
99
99.5
99.9
O_2 IN, CO OUT
CO IN, O_2 OUT
TANK → S, LINE → CELL
AIR IN, CO OUT
CO IN, AIR OUT
S, LINE → DRYER → CELL
S2, LINE → PUMP →

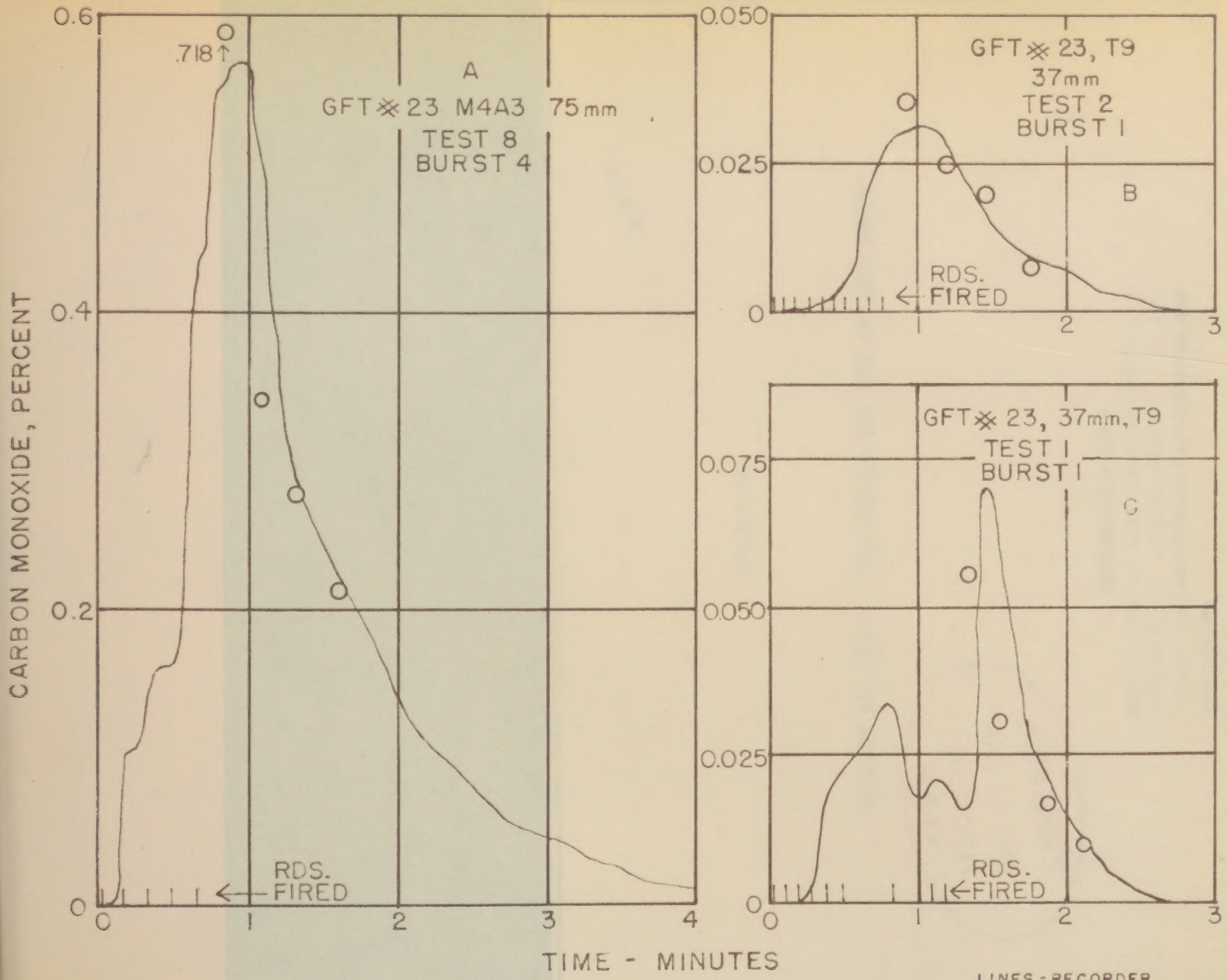


FIG. 5

Incl. #2

COMPARISON OF SNAP SAMPLES WITH RECORDER